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RHETT/EPDM Flight Hollow Cathode

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Under the sponsorship of the BMDO Russian Hall Electric Thruster Technology program two xenon hollow cathodes, a flight unit and a flight spare were fabricated, acceptance tested and delivered to the Naval Research Laboratory for use on the Electric Propulsion Demonstration Module. These hollow cathodes, based on the International Space Station plasma contactor design, were fabricated at the NASA Lewis Research Center for use with a D-55 anode layer thruster in the first on-orbit operational application of this technology. The 2.2 Ampere nominal emission current of this device was obtained with a xenon flow rate of 0.6 mg/s. Ignition of the cathode discharge was accomplished through preheating the active electron emitter with a resistive heating element before application of a 650 volt ignition pulse between the emitter and an external starting electrode. The successful acceptance testing of the Electric Propulsion Demonstration Module utilizing these cathodes demonstrated the suitability of cathodes based on barium impregnated inserts in an enclosed keeper configuration for use with Hall thruster propulsion systems.

Introduction

Over the last decade NASA hollow cathode technology for electric propulsion applications using xenon propellant has advanced to flight readiness status. The initial basis for this development was the need for reliable, long life discharge cathodes and neutralizers for ion thrusters as they transitioned from mercury to xenon propellant. The selection of xenon hollow cathodes for charge control on the International Space-Station (ISS) subsequently greatly accelerated this development and at the present time has resulted in a man-rated design which has demonstrated in excess of 25,000 hours of operation and over 30,000 on/off cycles.[1-4] At this time over 25 cathodes of this design have been built including the 10 flight units for the ISS. The same design with only very minimal modification has also been adopted for use by NASA for the NSTAR ion engines which will be used on the New Millennium Deep Space 1 spacecraft.[5]

Russian Hall thruster technology was being evaluated for use on Western commercial and government spacecraft concurrently with the development of advanced xenon hollow cathode technology. The successful evaluation of this technology had been succeeded by efforts to qualify and demonstrate advanced propulsion systems which utilize Hall thrusters. Much of this activity was sponsored by the Ballistic Missile Defense Organization (BMDO) through the Russian Hall Effect Thruster Technology (RHETT) program implemented by NASA.[6] The culmination of the RHETT development programs was a flight demonstration of a Hall thruster system via the Naval Research Laboratory's (NRL) Electric Propulsion Demonstration Module (EPDM).

EPDM will be the first operational use of a Hall thruster propulsion system onboard a western spacecraft. The Hall thruster which was selected for this system was the Thruster with Anode Layer (TAL) developed and manufactured by the Central Scientific Research Institute of Machine Building (TsNIIMash) in Korolev, Russia operating with a xenon hollow cathode supplied by NASA. This report summaries the characteristics of this cathode and the assembly and acceptance testing of two flight units for this program.

Design

For the RHETT/EPDM Hall thruster propulsion system, a cathode was required to supply a nominal current output of 2.2 amperes at a xenon flow rate of 0.6 mg/s. The ISS plasma contactor design was

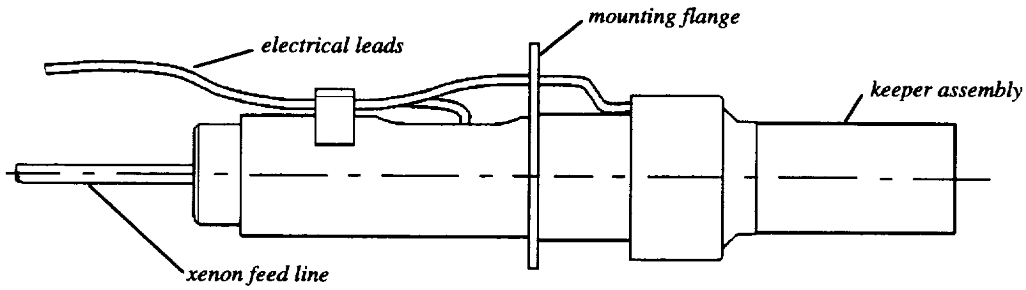

Figure 1: Schematic of the RHETT/EPDM Hollow Cathode

selected for this purpose. Although the range of output currents for this design is 2 to 12 amperes, which was not optimal for the EPDM application, the use of this design leveraged past experience and development efforts, thereby minimizing risk. The design is shown schematically in Figure 1. The cathode consists of approximately 30 parts and has a mass of approximately 250 grams. The overall length was 15 cm excluding the propellant tube. The design is an enclosed keeper hollow cathode configuration utilizing a low work function impregnated tungsten insert housed within a 0.64 cm diameter refractory metal cathode tube capped by a disk with an orifice in it. The material impregnated into tungsten insert was a 4:1:1 molar ratio of BaO, CaO, and Al_2O_3.

The cathode was self heating after ignition; however, prior to ignition a helical swaged heater was used for 7 minutes before ignition to bring the insert to operating temperatures. The heater was installed over the cathode tube in the region of the insert with an interference fit. Ignition was initiated using an outer keeper electrode consisting of a 1.9 cm diameter refractory tube capped with an orifice.

The keeper, cathode tube, and heater lead are all electrically isolated and retained within an electrical isolator. The cathode tube is also electrically isolated from the xenon propellant feed line by a second isolator. The xenon propellant line was a 0.3 cm diameter electropolished 316L stainless steel tube. Electropolished tubing was used in an attempt to minimize contamination of the insert. The functionality of the insert material is compromised by contamination of oxygen bearing compounds while at operating temperatures. As a result practices such as using electropolished tubing were adopted to keep contaminant levels to parts per million or less.

There were three electrical connections made with #16AWG wires: the cathode/heater return, keeper, and heater. This is shown schematically in Figure 2.

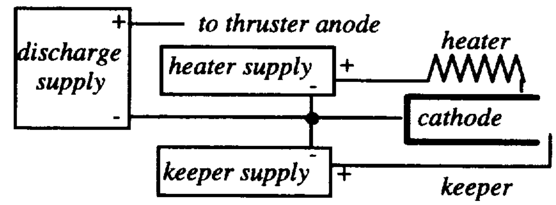

Figure 2: Electrical Schematic of the RHETT/EPDM cathode

The electrical requirements for operation of the cathode were an ignitor supply capable of supplying a 750±100 volt ignition pulse, a keeper supply capable of providing a 40 volts output at 3 amperes DC, and a cathode heater supply capable of operating in a current controlled mode at currents up to 8.5 amperes. The output voltage for the heater supply varied as the heater impedance varied over the range of operating temperatures. Typical impedances encountered were between 0.2 and 1.4 Ohms.

The assembly and acceptance testing of the two RHETT/EPDM cathodes was accomplished using product assurance protocols and processes developed for the flight plasma contactor cathodes. Each step in the assembly process was formally documented and approved by both an authorized assembly technician and a fabrication engineer. All parts were inspected prior to assembly. Redlined drawings showing actual dimensions were part of the documentation package that followed each cathode.

Cathode Acceptance Testing

Each cathode went through a series of test prior to delivery to NRL for integration into EPDM. The first tests were heater confidence tests conducted at the subassembly level. The swaged heater installed on the cathode tube went through a multi-step vacuum bake out procedure prior to a cyclic test. For each cathode heat 150 cycles were demonstrated during this test with no appreciable change in operating heater impedance.

Following assembly, each cathode went through an functional test consisting of the following: demonstration of diode-mode operation, demonstration of triode mode operation, and cyclic ignition. The diode tests were performed by operating the cathode at xenon flow rates between 0.83 and 0.45 mg/s at currents of 2.75 and 3 amperes to the keeper electrode. The results of this test for one of the cathodes which was subsequently vibration tested at the component level and performance acceptance tested a second time are shown in Figure 3. As can be seen there was a slight dependence of keeper voltage on cathode flow rate for a given keeper current.

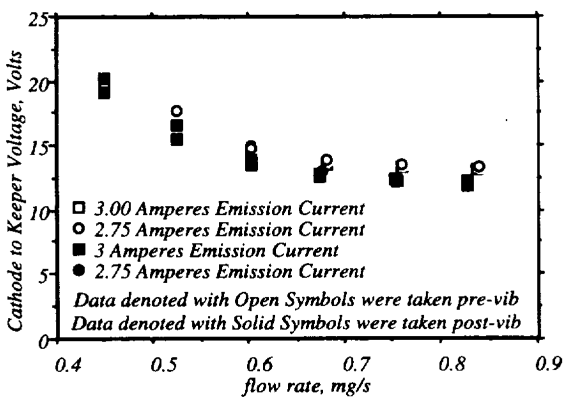

Figure 3: Pre-vib and post-vib diode-mode cathode performance acceptance test results.

Triode-mode operation was verified by operation at a xenon flow rates of 0.6, 0.68, or 0.75 mg/s with emission currents between 0.5 and 10 amperes. Cyclic ignition testing consisted of 10 successful ignitions with 50 minutes of operation for each cycle followed by 40 minutes off.

Both cathodes were vibration tested a minimum of one time. The flight spare cathode installed on the RHETT/EPDM flight cathode bracket was vibration tested at the component level. The flight cathode was vibrated at the sub assembly level. Vibration testing was conducted at 10 grms to verify workmanship. The input level for the component level vib in the y direction is shown in Figure 4. A schematic of this vibration test showing the coordinate axis and the 3-axis accelerometer location on the cathode is shown in Figure 5.

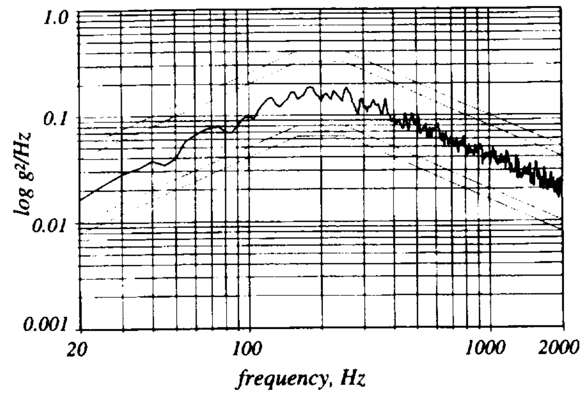

Figure 4: Y-axis vibration input levels for component level workmanship verification.

The input vibration levels shown in Figure 4 resulted in higher vibration levels at the end of the cathode than expected. This was primarily attributed to vibration amplification through the cathode bracket. Previous vibration testing of the plasma contactor design with a different mounting configuration showed no such amplification with 16.5 grms input. The resulting rms acceleration values measured in each direction for excitation at 10.5 grms in each axis are shown in Table 1.

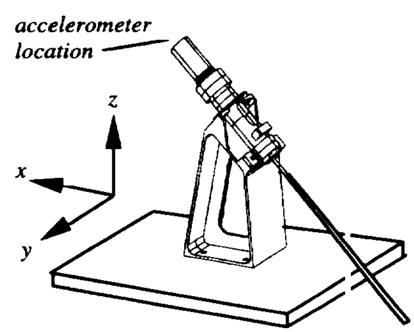

Figure 5: Component level vibration test schematic showing coordinate axis and 3-axis accelerometer location.

Table 1: measured vibration values (all values g rms)

excitation direction	x axis	y axis	z axis
x	16.0	22.4	27.0
y	8.7	45.4	12.2
z	17.0	12.2	15.7

Following vibration at these levels the heater impedance increased above the specified value by a fraction of an Ohm. This condition was corrected by

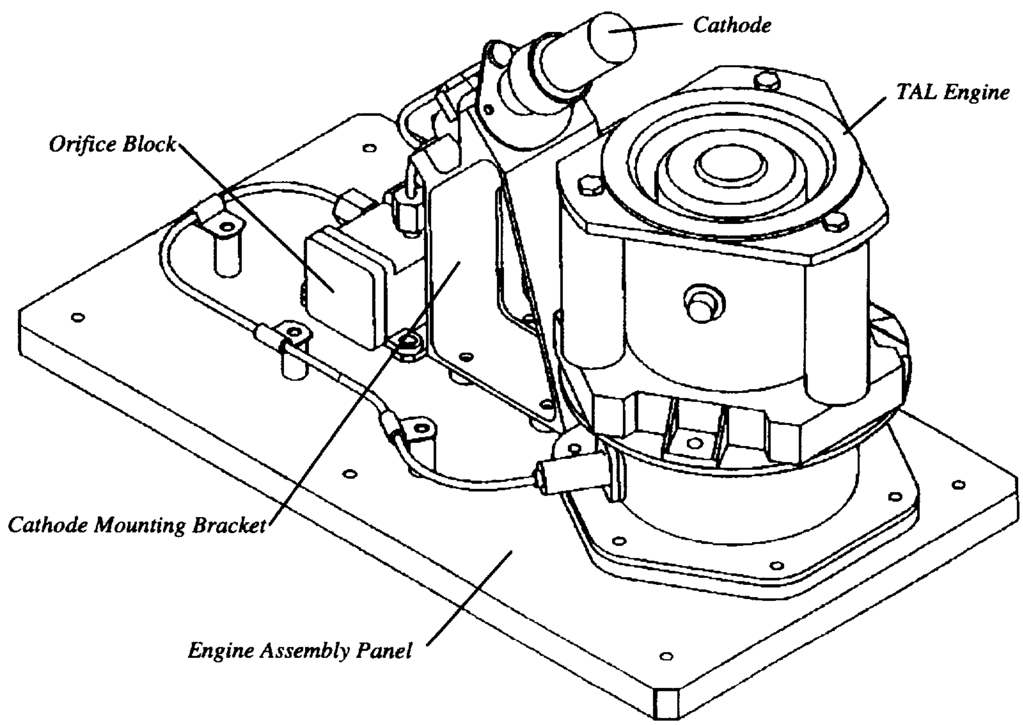

Figure 6: TAL engine panel subassembly

operating the heater. The change in impedance was speculated to be the result of an increase in the contact resistance between the sheath of the swaged heater and the cathode tube which also serves as the heater return lead. The thermal cycling associated with operation was thought to restore the position of the heater relative to the cathode tube to its pre vib location. Because the cathode is a sealed unit after completion of assembly this hypothesis could not be confirmed through a measurement of the cathode conductor to cathode sheath impedance, for example.

The impedance of the heater of the flight cathode was not measured following vibration, however, functional tests resulted no change in performance from the pre-vibration test data.

System Level Cathode Acceptance Testing

The flight cathode was integrated onto the TAL engine panel sub-assembly after completion of the successful performance acceptance test. A schematic of the TAL engine panel subassembly is shown in Figure 6 and a photograph of this same subassembly is shown at the end of this paper in Figure 7. At this point EPDM went through a battery of acceptance testing including vibration, shock, radiated and conducted electromagnetic emission and susceptibility testing, cold soak thermal testing, and thrust measurements. This series of tests are described in detail in companion papers.[7-9]

Interesting characteristics of this system as they pertain to the cathode are the use of a mechanical fitting to connect the cathode propellant feed line to a fixed orifice which provided the required xenon throughput, the clamping of the thruster body to cathode emitter potential to minimize problems during thruster ignition, and the use of electropolished or microcleaned components throughout the propellant feed system to minimize the possibility of contamination of the cathode insert. More details on the feed system can be found in the paper by Osborn.[10]

Conclusions

Two xenon hollow cathodes, a flight unit and a flight spare were fabricated, acceptance tested and delivered to the NRL for use on the RHETT/EPDM propulsion system. These hollow cathodes, based on the international space station plasma contactor design, were fabricated at the NASA Lewis Research Center for use with the D-55 anode layer thruster in the first on-orbit operational application of this technology. The 2.2 Ampere nominal current output of this device was provided with a xenon flow rate of 0.6 mg/s. Starting of the cathode discharge was accomplished through preheating the barium impregnated tungsten emitter with a swaged heated before application of a 650 volt ignition pulse between the cathode emitter and the keeper electrode. The successful acceptance testing of the Electric Propulsion Demonstration Module utilizing this cathode demonstrated the suitability of cathodes based on barium impregnated inserts in an enclosed keeper configuration for use with flight Hall thruster propulsion systems.

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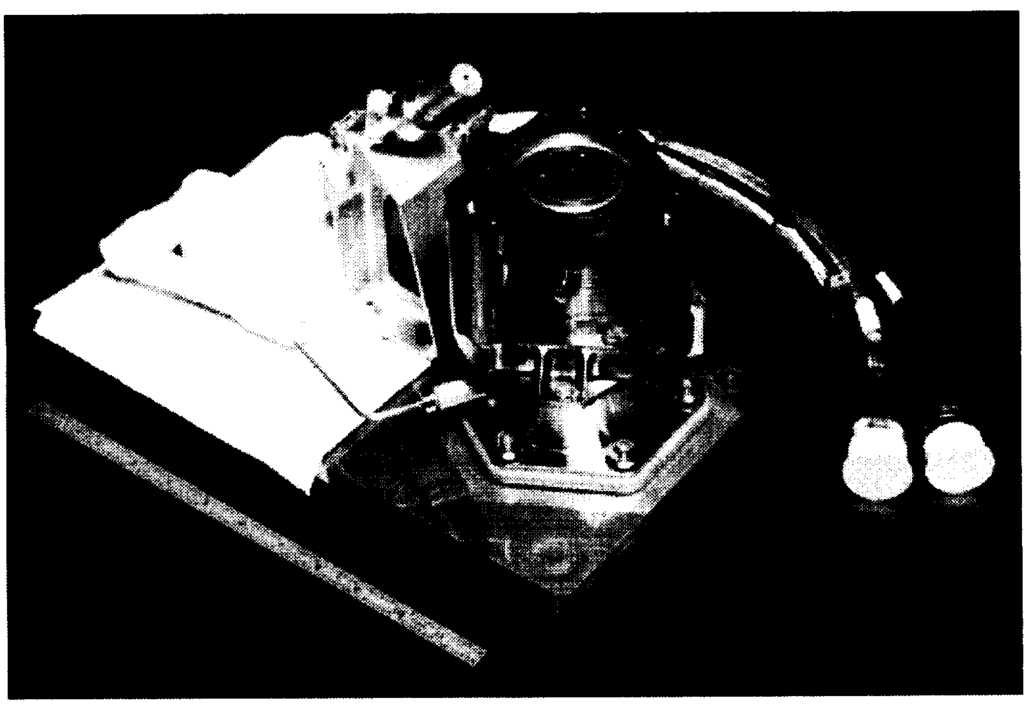

Figure 7: Photograph of the EPDM flight TAL engine panel including cathode

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